Overpotential*

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Introduction

The subject of overpotential is characterized by the width of its scope. It embraces the whole of electrode process chemistry, and electrode process chemistry might be said to constitute in magnitude and importance more than half of electrochemistry. It is the determinative fact of interest in the important and little-examined branch of the study of the velocities of reactionsle—ectrode kinetics; a summary of the many processes which it affects is shown in Fig. 1.

A few examples of the functions of overpotential illustrate this width of scope. Thus, it influences the physical nature of an electrodeposit and contributes to the determination of the amount of energy which the electrodeposit requires. It is the basis of a new method of analysis and a new research tool of use in practically every branch of chemistry—polarography. It is one of the main determining factors in certain types of metallic corrosion. It enables us to separate deuterium electrolytically from hydrogen, still the largest scale method for the production of isotopes. Electrolytic reduction of organic and inorganic compounds takes place in quantity and in reaction paths primarily as a function of the overpotential developed in the reaction. Last, but from the viewpoint of the future by no means least, it entirely governs the practicability of the efficient production of energy by means of fuel cells.

It is a little surprising, therefore, to find that until relatively recently the subject of overpotential was one relegated to the last chapter of textbooks, where it received brief and extremely confused treatment, generally under the name of various types of "polarization."

Historical Observations

The first rational observations on overpotential at individual electrodes were by Jahn and Schönrock (1) in 1895 who suggested the equation between potential and current generally attributed to Tafel (2) (1905), namely,

$$\eta = a - b \log i \qquad \text{(I)}$$

where a and b are constants dependent upon the metal, and η is the overpotential at a current density of i. Tafel's work stands out independently of his enunciation of equation (I) because he formulated the first rational theory of hydrogen overpotential, namely, that the extra potential compared with the reversible potential necessary for the reaction to proceed at a definite rate was dependent upon the concentration of hydrogen atoms on the electrode surface, and that the rate-determining reaction was

$$H + H \rightarrow H_2 . \qquad \text{(II)}$$

Notwithstanding Tafel's work, progress on the overpotential associated with electrolytic gas evolution was retarded for many years by the persistence of experimenters who believed that for one gas and one metal there was one overpo-

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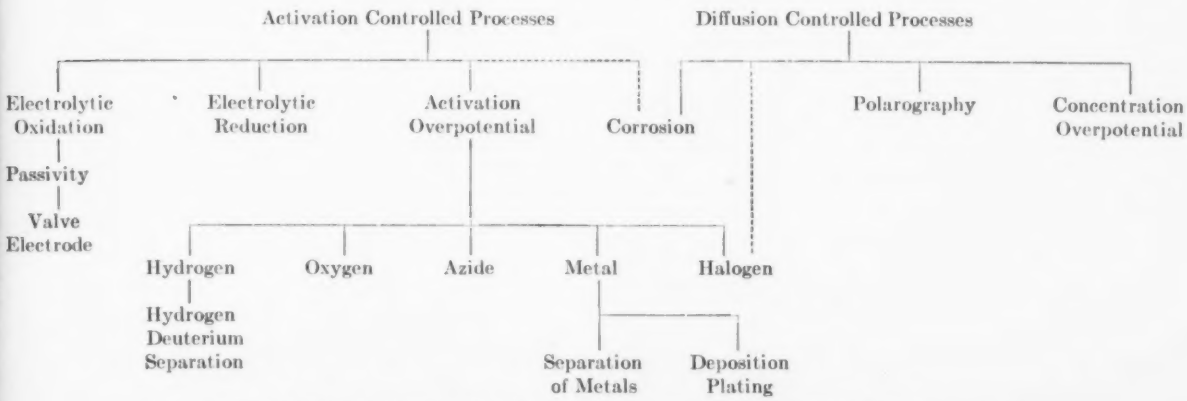

FIG. 1. Classification of irreversible electrode processes (from Parsons, Thesis, London, 1948).

tential, independent of current density, and that this was measured by the potential at which bubbles became visible to the naked eye. This method was not completely disproved until the work of Baars (3) (1928), who showed, by determining the current passing at any potential by means of the hydrogen evolved, that hydrogen was evolved continuously at all potentials down to the reversible potential. Bubble overpotentials thus have significance only as measures of the overpotential which has to be set up on various metals before the rate of evolution is large enough to form visible bubbles, a rate depending on many secondary factors connected with the state of the electrode-solution interface.

An often neglected contribution was made to the theory by Smits (4) in 1922. This worker suggested that the discharge of hydrogen

$$H^+ + e \rightarrow H$$

could also be the cause of hydrogen overpotential. Smits made this suggestion as a corollary of a rather obscure theory of allotropy which he had developed at that time and the suggestion was neglected until 1930, when Erdey-Grúz and Volmer (5) gave it mathematical treatment. This treatment, however, involved the error of assuming that the concentration of ions which undergo discharge was the same as that in the bulk of the solution, and the correction to the Erdey-Grúz-Volmer equations was given by Frumkin (6) in 1933. The last fundamental contribution of prewar years was that of Horiuti and Polanyi (7) (1935) who showed how the heat of adsorption of hydrogen upon a metal affected the rate of discharge, thus making it possible to understand the dependence of hydrogen overpotential upon the metal on the basis of a rate-determining discharge, as well as a slow combination viewpoint.

To some extent in parallel to these advances, a number of workers tended toward belief in a general explanation for all cases of overpotential. Hammet (8) was the first to point out clearly the improbability that one rate-determining reaction (e.g., electron transfer from the metal to the reacting species) could be the basis for the many manifestations of overpotential. The opposite trend, namely, to describe many different types of overpotential with a large number of new terms, is also to be deprecated, because these terms (e.g., reaction overpotential, transmission overpotential, etc.) usually refer to the same type of reaction under different, but not often easily determinable, guises.

While these variations in the progress of the study of hydrogen overpotential were taking place, even less progress was made with the fundamental study of the electrode kinetics of other reactions. Even with the activation overpotential associated with metal deposition it was generally thought until as late as 1937 that this phenomenon was particularly exhibited by Fe, Co, and Ni. In this year, however, the first accurate measurements of the rate of metal deposition at a given overpotential were made by Ruyter, Juza, and Poluyuan (9) and the generality of the existence of metal activation overpotential was realized.

Factors Vitiating Progress

The tortuous progress made by electrode process research hitherto indicates the presence of considerable experimental difficulties, for much of the lack of progress has been due to difficulties in obtaining agreement between workers of various schools. The first of these concerns the measurement of potential itself. The usual Luggin capillary method (10) for obtaining the potential of a single electrode is associated with the possibility that an ohmic potential difference exists between the end of the capillary and the electrode and this potential difference, as many earlier results showed, may be erroneously included in the measured overpotential. Newbury (11) (1916) earned the distinction of inventing the commutator method of measuring overpotential, namely, the method in which a commutator is used to subject the electrode to alternative but not simultaneous polarization and measurement. Although successful in principle, use of the method led to considerable confusion until it was realized that the decay of overpotential on open current was often so rapid that the measured result was far less than the correct one with current passing. Hickling (12) (1937) overcame these difficulties by using an electronic circuit in which the time during which the overpotential decays is extremely small (10^{-4}–10^{-5} sec). Extrapolation to zero time gave the overpotential at the electrode during passage of current. Comparison with the direct method for the same system showed that the method is successful up to about 1 amp/cm^2 in normal aqueous hydrochloric acid solutions. At higher current densities the decay is too rapid for the present state of development of even this method. At very high current densities, recent successful use has been made of the direct method by utilizing several cathode tips at various distances from the electrode, and extrapolating results obtained on these to zero distance from the electrode (13). At present it appears that so long as the direct method is correctly used it is adequate and certainly less laborious. In cases where resistive films are suspected on the electrode surface, however, only the commutator method is successful.

The second great difficulty which meets workers on overpotential is the effect of trace impurities. Poison effects have been examined in hydrogen overpotential studies for many years. Bockris and Conway (14) (1949), however, were the first to examine the lower limit at which trace impurities affected the velocity of hydrogen evolution at a given potential: these workers found the remarkable result that as little as 10^{-10} gram moles per liter could affect the overpotential. It is impossible to remove these traces by ordinary chemical methods and it has become essential to subject the solutions to pre-electrolysis, namely, to purification by prolonged passage of current onto an auxiliary electrode before introduction of the test electrode (15). With this evidence of the effect of such minute traces upon one electrode reaction it is clearly essential to subject other systems to examination for trace poison effects before results can be trusted.

Poisons such as As_2O_3 are by no means the only ones to cause concern. Thus, it can be shown that the limiting current for the diffusion of a depolarizer to a cathode is given by

$$i_L = \frac{DzF}{\delta} c,$$

where D is the diffusion coefficient in gram ions/cm^2/sec, $\mathbf{F}$ is the Faraday in coulombs, δ is the thickness of the diffusion layer in cm, z is the number of electrons used up in the electrode reaction, and c is the concentration (strictly, activity) of the substance being deposited in gram ions/cm^3. In an unstirred solution, $\delta \simeq 0.05$ cm; $\mathbf{F} = 96{,}500$. Hence

$$i_L = 1.93\ 10^3\ Dzc'$$

where c' is the (more generally used) concentration in gram moles per liter. For the reduction of oxygen, $z = 4$; also

$$D_{O_2} \simeq 1.8 \cdot 10^{-5}.$$

Hence,

$$i_L \simeq 0.14\ c'.$$

If the current density of polarization has, for example, the medium low value of 10^{-6} amp/cm^2, the presence of only $1.4 \cdot 10^{-5}$ gram moles of oxygen per liter would tend to reduce the measured overpotential to zero. To make successful measurements at current densities of 10^{-6} amp/cm^2 we therefore need to reduce the oxygen concentration to below about

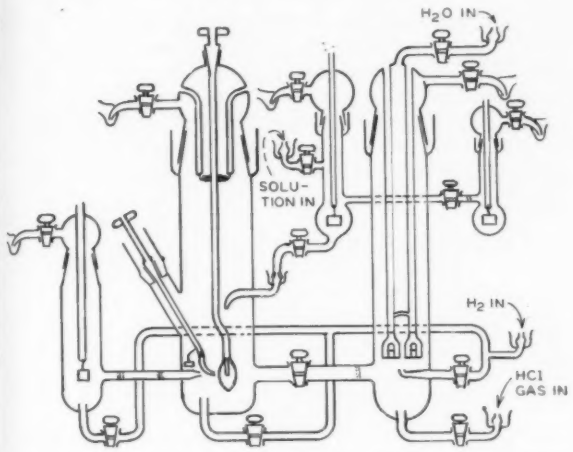

FIG. 2. Cell used in the determination of hydrogen overpotential.

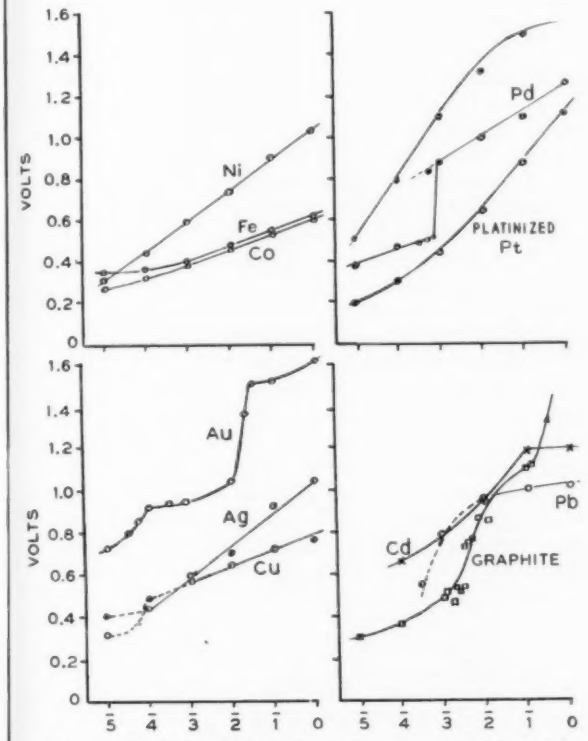

FIG. 3. Typical relations between overpotential and log current density in the evolution of oxygen.

10^{-6} gram moles per liter, namely to about 1/1000th of the amount present in a solution in equilibrium with air. If we wish to decrease the current density to really low values (e.g., 10^{-12}) the oxygen concentration would have to be reduced correspondingly. A reduction to this concentration has only been achieved by Bowden and Grew (17) (1947); these workers used a full high vacuum system and polarized their cathodes through a protective membrane of highly conductive glass. For current densities down to about 10^{-8} amp/cm^2 less stringent evacuation of the apparatus before measurement is required. However, the fact that traces of tap grease or rubber are known to vitiate experiments makes the ordinary type of electrolytic cell undesirable, and Frumkin and coworkers (18) (1936) used solution-sealed ventils. A development of this type of cell due to Bockris and Conway (19) (1948) is shown in Fig. 2.

In studies of anodic polarization the danger of oxygen depolarization is absent but the formation of oxide (or other) films on the electrode surface brings more intrinsic difficulties. These films probably change with current density and give rise to overpotential-log current density relations (Tafel lines) which defy any straightforward interpretation (20) (Fig. 3).

Study of metal overpotentials has been beset with a similar kind of difficulty because as crystal formation takes place with the deposited metal, so the nature and real area of the

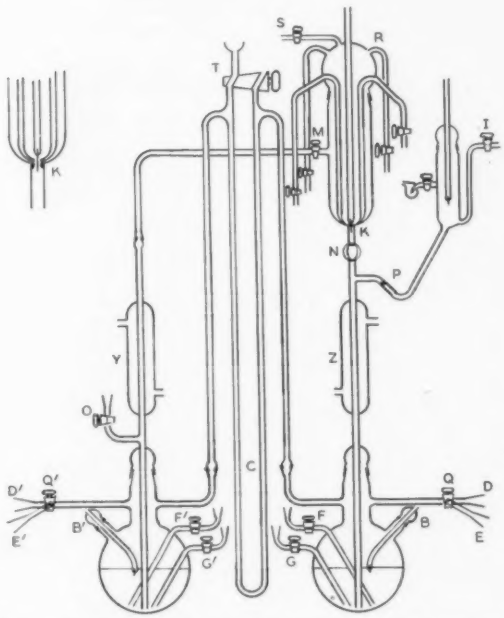

FIG. 4. General view of apparatus used in the determination of overpotential at very high current densities.

electrode surface changes and, consequently, the Tafel lines obtained are highly complex. Use of cathode-ray oscillographic techniques has considerably reduced these uncertainties in more modern work, the overpotential being measured directly after the double layer has become fully charged (9). This is a method which may be of considerable use in most overpotential studies.

Some Examples of Recent Experimental Advances

An apparent anomaly in the kinetics of hydrogen evolution, stressed in recent years (21), concerns the apparent tendency to attain a limiting value of overpotential on certain metals at high current densities. This is a highly surprising result and one which gives rise to fundamental theoretical difficulties. However, when the relevant experiments were repeated using solutions purified by pre-electrolysis, linear Tafel lines were obtained in place of those showing a limiting overpotential (22). The difficulty remained, however, to establish what caused the previously found deviations. It was found

that the linear Tafel line could be converted into the one exhibiting a tendency toward an anomalously low value of hydrogen overpotential at high current densities by the addition to the solution of traces of H_2S (Fig. 4). It can be shown that H_2S would tend to be adsorbed upon an electrode only at more negative potentials. It is likely that, being adsorbed in the electrode double layer, discharge of protons occurs from H_2S, this being probable compared with discharge from water because of the much lower dissociation energy of the S—H bond (87.5 kcal) compared with the O—H bond (110.2 kcal) (22).

The study of the kinetics of hydrogen evolution at very high current densities is of considerable interest because expectations based upon various experimental models can only be tested under these conditions. Experimental difficulties are severe because of vitiating factors such as concentration overpotential, heating effects due to the comparatively high currents which must be used even with electrodes of very small area, and, above all, to the possible presence of a considerable component of ohmic overpotential. Azzam and Bockris (13) (1950) avoided these difficulties by use of a cell

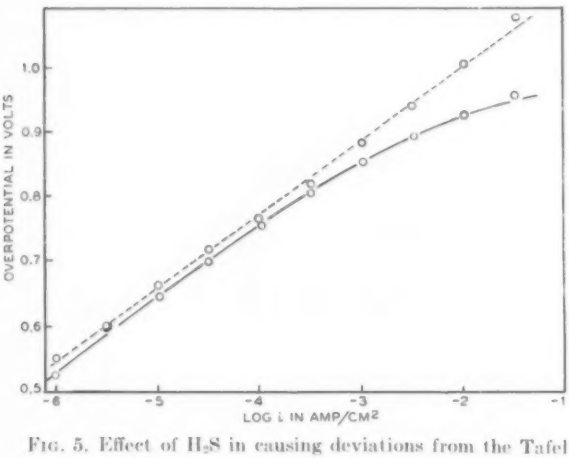

FIG. 5. Effect of H_2S in causing deviations from the Tafel equation at high current densities. Dotted line in absence of H_2S; full line after addition of trace of H_2S.

in which rapid streaming of the electrolyte over the surface of the electrode was maintained and in which the overpotential was measured with several Luggin capillaries at different distances from the electrode surface (see Fig. 5). Among the most interesting results obtained was that of the Tafel line for smooth platinum electrodes. It was found that the b value of the Tafel equation had the value of 0.029 (temp = 25°C) at current densities up to about 1 amp/cm², but that at high current densities a limiting current was at first obtained, to be succeeded at still higher current densities by a linear Tafel equation with a b value of 0.116. This proves in the clearest manner that the mechanism of hydrogen evolution at one cathode in the same solution may be different at various current densities.

A quite different aspect of recent important experimental work on overpotential is that of Fischer and Heiling (23) (1950), who examined the overpotential on the inner and outer surfaces of an iron beaker, both sides being in contact with the solution, but one side only being subjected to polarization. These authors obtained a "transfer" of hydrogen overpotential through the cathode from the polarization to the diffusion side. The most interesting aspect of their results, however, is that they observed a b value of the Tafel equation of 0.12 on the polarization side, while on the diffusion side the value was approximately 0.03. This has important implications. On the diffusion side the only possible mechanism for the slow stage is the combination of hydrogen atoms so that the observed b value of 0.03 offers direct experimental proof that this value is associated with Tafel's original mechanism, as expected theoretically. Their results have a more important aspect, however, for they indicate that a considerable concentration of hydrogen exists on the electrode surface in the steady state during polarization at an iron surface. Theory shows that if this is so and the associated value of b is about 0.12, the slow stage in the evolution or the polarization side is likely to be the electrochemical mechanism

$$H_3O^+ + MH + e \rightarrow H_2 + H_2O + M.$$

Theoretical Aspects of Overpotential

It is clearly impossible to attempt a discussion of the theory of overpotential in general, not only because of the very considerable scope of this topic but because of the lack of comprehensive contributions which have as yet been made to the whole field. While the discussion, therefore, will have to be limited principally to hydrogen overpotential, generalizations will be attempted wherever possible.

If the initial considerations are further limited to the mechanism of the hydrogen evolution reaction in aqueous acid solutions, one reaction path only is of modern interest. This is the discharge from hydroxonium ions followed by one (or both) of the two possible desorptive reactions. These are: (*a*) the electrochemical desorption reaction in which a hydroxonium ion displaces an adsorbed hydrogen atom to give, together with an electron, molecular hydrogen, and (*b*) the atomic hydrogen combination reaction.

The theory of slow prototropic transfer (24) is not considered as probable here because (*a*) the principal experimental basis to it has been shown to be illusory, and (*b*) the theory comes into direct conflict with experiment in respect to the effect of the variation of hydrogen overpotential with pressure, and the expected pH and salt effects.

The theory of hydrogen overpotential can perhaps most revealingly be attacked by what may be called the steady state method (25). However, some general equations for electrode reactions, recently formulated by Parsons (26), give rise to important criteria. By assuming that the over-all reaction tends to occur reversibly at low current densities while at the current densities at which the mechanism is to be determined the back reaction is negligible, it is possible to decide upon the rate-determining reactions of any electrode process. Let the over-all reaction be

$$xX + mM^y + ze_0 \rightarrow wW + nN^{(my-z)/n}$$

and the rate-determining reaction be

$$x'X + m'M^y + \lambda e_0 \rightarrow w'W + n'N.$$

Let E_p and E_q be the electrical components of the electrochemical potential of two states, respectively, just before and just after the activated state. Then, a term β is defined such that

$$E^* - E_p = \beta(E_q - E_p).$$

where E^* is the electrical component of the free energy of the activated state. From these definitions, direct application of the theory of rate processes shows that

$$\vec{i} = \frac{z}{\mu} \mathbf{F} a_x^{x'} a_m^{m'} \frac{kT}{h} \exp\left[\Delta G^* + (1-\beta)p + \beta q + \beta\lambda\Delta\phi\mathbf{F}\right]$$

where z/μ = ratio of equivalents in over-all reaction and rate-determining step; $\mathbf{F}a$ = faraday × activity; kT/h = frequency factor; ΔG^* = free energy of activation of the rate-determining reaction; p = the change in electrical free energy in transfer of sufficient of the initial state to undergo one rate-determining reaction from the initial state to state P; q = the change in the electrical free energy in a similar transfer from the final state to state Q; λ = the number of electrons which must pass from the cathode for the rate-determining reaction to proceed by one step; and $\Delta\phi$ = the galvani potential difference between the electrode and the bulk of the solution. From the equation various derived equations can be obtained, such as:

$$\left(\frac{\delta\eta}{\delta \ln a_x}\right)_{T,\Delta\varphi} = x' - \frac{1-\beta}{RT}\left(\frac{\delta p}{\delta \ln a_x}\right)_{T,\Delta\varphi} - \frac{\beta}{RT}\left(\frac{\delta q}{\delta \ln a_x}\right)_{T,\Delta\varphi}$$

The differential coefficient on the left-hand side is determined experimentally; $\left(\frac{\delta p}{\delta \ln a_x}\right)$ and $\left(\frac{\delta q}{\delta \ln a_x}\right)$ are calculated theoretically for various hypothetical possibilities and the value of x' is then calculated. The postulated reaction, which then gives x' in agreement with the value expected for this reaction, is taken as the rate-determining reaction.

The present state of the theory reveals that the most important determinations to make in order that the mechanism of an electrode reaction may be determined are the following. (*a*) The b constant of the Tafel equation. (*b*) The electron number λ; determination of this quantity involves measurement of the differential coefficient of overpotential with respect to current at conditions of very low overpotentials. Often, therefore, as for example with the hydrogen evolution reaction upon mercury surfaces, determination of λ is prohibitively difficult. (*c*) The pH and salt effects as indicated in the general equations above. In certain cases it may also be of help to obtain ΔH_0, the heat of activation of the reaction at the reversible potential, and the potential of the electrocapillary maximum. These quantities aid decisions between detailed mechanism by means of some of the theoretical equations already presented by the author (25). The determination of the transfer of overpotential through an electrode may be a useful distinguishing factor, as exemplified by the work of Fischer and Heiling.

Attempts to apply statistical mechanical methods to calculate the absolute rate of electrode reactions have hardly begun (27). However, it is relevant to note a recent important advance in this work (28). In this, the expressions for the heat content of the initial and final states of the proton discharge reaction were obtained by considering certain thermodynamic cycles connected with these states. The variation of these quantities with distance was found by expressing (for the initial state) the solvation energy of the proton in the form of a Morse equation and in the final state the heat of adsorption of hydrogen atoms by a similar method. Potential energy curves could then be constructed for the initial and final states as a function of distance from the electrode, and the height of the intersection of these above the curve for the initial state gives the energy of activation with respect to the initial state. An estimate of the entropy of activation can be made by considering that the entropy of the activated state differs from that of the final state essentially by the loss of the two degrees of freedom of the adsorbed hydrogen atom. In this way the free energy of activation of the reaction may be quantitatively established and then, by the use of the general equation of the transition state theory, the absolute value of the current may be obtained. Within the (fairly wide) limits of error involved in these calculations, agreement with experiment has been achieved at least for mercury and nickel electrodes.

Future Work

The most pressing requirements of work on electrode kinetics is that of further extensive experimentation under standard, controllable conditions of the state of the solution and the electrode surface, and directed toward the determination of parameters of critical, theoretical importance as diagnostic criteria of mechanism. In particular, other reactions, e.g., irreversible oxidation or reduction processes should be studied, in addition to the studies on hydrogen, oxygen, and metal overpotential. The second most pressing requirement is that theoretical computation on a statistical mechanical basis should be intensively pursued, so long as a careful estimate is always made of the limits of error which the calculated quantities involve.

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Electric Furnace Smelting and High Temperature Chemistry*

Marvin J. Udy†

To properly conduct chemical reactions at high temperature in molten media, a good electric furnace and a good electrochemist are essential.

The metallurgist is usually the man in charge of electric furnace melting operations. He is trained in metallurgy, and is proud of his calling. The good metallurgist must be a good chemist and, in dealing with the electric furnace, a good electrochemist. Unfortunately our colleges and universities are no longer teaching courses in electrochemistry as such. Industry needs electrochemists in the ever growing use of the electric furnace, and this need will be greater as we are called upon to treat lower and lower grade ores, to supply our needs for metals.

The electric furnace is a highly efficient furnace for melting at high temperatures. It is possible to attain 65 to 75 per cent energy efficiency at temperatures up to 1300°C, and higher. The specific heat of most slags is low, and most slags are capable of adjustment to carry out the desired chemical reaction.

Processes designed to make available all valuable constituents of the ores, no matter how small, will ultimately be required and the electric furnace is one medium by which such can be accomplished. Electric furnace smelting and the application of high temperature chemistry offer, I believe, many opportunities for the electrochemist.

Size of Electric Furnace Smelting Industry

In the ferro alloy field 2,000,000 tons of ferro alloys were produced in 1950. From the estimated installed electric furnace capacity for ferro alloys in the United States of 640,000 kw in 1950, it is estimated that, of the total 2,000,000 tons produced, about 800,000 tons were produced in the electric furnace. The remainder was produced as ferromanganese, spiegel, and silvery pig in the blast furnace. Data for a few of the larger industries are given in the Table.

To this list should be added magnesium, which has reached a production of 13,000 tons per year with an installed capacity of 26,000 tons, exclusive of Government-owned plants, some of which are being reactivated. We should also add zinc, copper, nickel, antimony, slag wool, fused alumina, carborundum, fused refractories, special foundry irons and steels, and many others.

The kw capacity per unit for the phosphorus furnace has grown from 400 kw in 1918 to 18,000 kw at present, and now 25,000 kw furnaces are contemplated. The production of calcium carbide long ago reached 18,000 to 24,000 kw, and now 25,000 and 30,000 kw units are being considered. New ilmenite smelting furnaces are starting off with 18,000 kw, and 10,000 kw ferromanganese furnaces are being designed. The end of this increase in unit capacity is not in sight.

Types and Design of Electric Furnaces

The two principal types of electric smelting furnaces in use today are both of the arc-resistance type. They may be operated full "open-arc" where the heat is principally generated in the arc, or they may be operated fully covered (submerged arc) where the heat is generated partly in the arc and partly in the slag. Full resistance heating is principally used in processes such as the production of magnesium, aluminum, and carborundum.

The electric furnace may be either single-phase, two electrode; single-phase, top and bottom electrode; or three-phase with three electrodes. The particular operation determines the choice of furnace but today the three-phase furnace is used wherever possible.

In melting and refining furnaces, as typified by the electric steel furnace, the heat may be developed entirely in the arc or in the arc and the slag. This type of furnace lends itself to a high degree of control of the slag composition and chemistry. It is dependent primarily on high voltage for increased loads (kw input) because of the high arc resistance.

The design of the electric furnace should be governed by the condition that is desired at the tip of the electrodes, such as the temperature of the molten products, slag composition, metal compositions, and heat concentration and distribution. It is not always possible for the electrical engineer to design what the electrochemist most needs, but usually where the two get together and each understands the requirements and limitations of the problem, they are able to accomplish the conditions required for any particular chemical reaction that is to be carried out.

Product	Tons yearly	kw ton	Yearly kwhr (Millions)	Sustained rate in kw
Calcium carbide	605,000	3,000	1,815	210,000
Phosphorus	125,000	14,000	1,750	202,000
Aluminum	715,000	20,000	14,300	1,655,092
Ferro alloys	800,000	2,000 to 13,000	660	755,000
Stainless steel ingots	800,000	800	640	740,000
Alloy steels	6,000,000	600	3,600	410,000

From the electrochemist's point of view the most important features of design are: Voltage, electrode spacing, size of material to be smelted, heat distribution, electrode size, and peripheral ohm factor.

Phosphorus Production

The chemistry involved in the production of phosphorus is represented by the following equation:

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C = P_4 + 6CaO\,SiO_3 + 10CO.$$

Over-reduction can produce silicon, calcium carbide, calcium phosphide, and other products. A close carbon balance is required and maintained at all times, even though some single furnaces smelt 200 tons per day or more.

High Carbon Ferro Chrome

High carbon ferro chrome production is more complicated, and there are more reactions to control. The carbon reduction of chrome ore is represented by the following equation:

$$FeO\,MgO\,Al_2O_3\,Cr_2O_3 + 4C = Fe\,Cr_2 + MgO\,Al_2O_3\,SiO_2 + 4CO.$$

Here MgO, Al_2O_3, SiO_2 as well as FeO and Cr_2O_3 can all be reduced with carbon. In addition the chromium has a high

* Excerpts from a paper presented at the meeting of the American Institute of Chemists, May 10, 1951, Niagara Falls, Ontario. The complete paper appears in *Canadian Chemical Processing*, XXXV, 626 (1951).

† Mr. Udy, Consulting Engineer in Niagara Falls, New York, is a Vice-President of The Electrochemical Society.

affinity for carbon and will pick up as much as 10 to 11 per cent carbon. The usual product desired is ferro chrome containing 68 to 70 per cent Cr, 4 to 6 per cent C, and minus 1 per cent Si.

To meet these specifications the electrochemist, in addition to proper control of the correct electrode size, voltage, and peripheral ohms, must control the slag composition to give a correct temperature for the particular result desired. Low temperature slags will give high carbon in the metal. Low temperature slag will also result in metal freezing on the bottom. High temperature slags will give 4 to 6 per cent carbon in the metal, but may give high chromium oxide in the slag. Carbon balance is extremely important and must be held within close limits. Carbon in quantity and size effects the position of the electrodes in the furnace with relation to the bottom. It determines silicon and aluminum content of the metal. Too much fluxing will result in high slag volume and high losses of metal in the slag.

In spite of all these variables the electrochemist, year in and year out, and with electrode tips under 3 ft to 4 ft of charge (and always smelting and reducing metal into the already molten slag and metal) daily holds the composition of the metal within the limits of the specifications of 4 to 6 per cent carbon, 0.50 to 1 per cent silicon, and 68 to 70 per cent chromium.

Melting and Refining

The best classic example, and the most advanced process involving melting and refining in the electric furnace, is probably the production of stainless steel and alloy steels. Here the electrical engineer, the chemist, and the metallurgist have combined their skills with remarkable results in both basic chemistry and physical chemistry at high temperatures.

Unlike the submerged arc smelting furnaces, the electric steel furnace is an open-arc furnace in which batches of steel are produced. The operations consist of charging, melting, and refining. A few of the chemical reactions involved in the refining are represented by the following equations:

$$C + FeO \rightleftarrows CO + Fe$$
$$Mn + 2FeO \rightleftarrows MnO \text{ in } FeO + Fe$$
$$Mn + FeO \rightleftarrows MnO \text{ (Mn silicate slag)} + Fe$$
$$Si + 2FeO \rightleftarrows SiO_2 + 2Fe$$
$$Mn + FeS \rightleftarrows MnS + Fe$$
$$FeS + CaO + C \rightleftarrows CaS + CO + Fe$$
$$8FeO + 2P \rightleftarrows 3(FeO)\ P_2O_5 + 5Fe$$
$$N\ CaO + P_2O_5 \rightleftarrows N\ CaO\ P_2O_5$$
$$2Cr + 3FeO \rightleftarrows Cr_2O_3 + Fe$$
$$3Si + 2Cr_2O_3 \rightleftarrows 3SiO_2 + 2Cr_2$$

These reactions are all reversible and are conducted at high temperatures, at or near 1800°C. They can take place in the slag, at the slag metal interface or between the dissolved oxides and metals within the molten steel. In addition there are the elements such as hydrogen and nitrogen to control. Hydrogen is a problem of occluded gas while nitrogen is one of alloying, both different problems and requiring different treatment.

Under such complex conditions it is not an easy task to meet specifications for quality alloy steels. The electrochemist and metallurgist, however, are meeting very close specifications both as to chemical analysis and physical properties. The slags are controlled as to composition, removed as needed to accomplish a definite result, and replaced with another slag to accomplish another result. The electrochemist must prevent reversion of unwanted elements like phosphorus and sulfur to the metal once they are in the slag. He must prevent oxidization to the slag, of wanted metals like manganese and chromium. He must add oxidizers, deoxidizers, and recarburizers, and must be able to control oxidation, deoxidization, or recarburization in a matter of minutes. He must add silicon, titanium, columbium, boron, tungsten, and vanadium—all oxidizable elements—in very small percentages and make a high recovery of each. He must add nickel and molybdenum to meet very close specifications and not lose other elements by oxidation while doing it. He must maintain at all times the correct temperature and slag composition for the correct conditions for the reactions to take place. In addition the metal must leave the furnace at sufficiently high temperature to allow teaming into ingot molds, without skulls in the ladle, and to obtain sound, clean ingots.

The chemistry and metallurgy involved in electric furnace steel making, both basic and physical, have been highly developed by many excellent electrochemists, metallurgists, and engineers. They are producing millions of tons of steels and foundry irons, meeting seemingly impossible specifications.

Surely the electrochemistry applied in making steel in the electric furnace is a fine example of what the good electrochemist can do in controlling chemical reactions at high temperatures. The 800,000 tons of stainless steel ingots and some 6,000,000 tons of low alloy steels and foundry irons and steels produced in the electric furnace are evidence of the skill attained by electrochemists in the steel industry of the United States.

Selective Reduction

The selective reduction and separation of one metal from another at high temperatures involves a good knowledge of slag compositions and skill in the use of the electric furnace. It is not improbable that many of our low grade ores will ultimately be treated in the electric furnace for the economic recovery of the valuable metals. It is not at all impossible to develop the skill of the electrochemist in other operations as it has been developed in the steel industry and in other industries involving electrochemistry.

A beginning has been made in the selective reduction of iron from ilmenite by the Quebec Iron and Titanium Company which is already operating large 18,000 kw furnaces for the purpose of removing iron from ilmenite and which soon expects to be treating 1500 tons of ilmenite per day.

Processes are being developed for the selective reduction of iron and impurities such as phosphorus, lead, copper, and arsenic from our low grade manganese ores in order to make them amenable to the production of standard ferromanganese, at least in times of emergency.

Processes for the separation of the easily volatilized metals such as magnesium, potassium, zinc, lead, or antimony are contemplated and being developed. The phosphorus furnace is a good example of the volatilization of the valuable constituent while producing a high temperature slag, and of what might be done with other volatile metals.

Conclusion

The electric furnace is, in reality, an instrument for carrying out chemical reactions at high temperature. Properly designed for the particular purpose for which it is to be used, and in the hands of a good electrochemist, it is capable of maintaining conditions that will produce the required results with a high degree of accuracy.

The electric furnace and high temperature chemistry present many opportunities for the well-trained and imaginative electrochemist.

Candidates for Office—1952-53

J. C. Warner

Presidential Candidate

J. C. Warner, President of Carnegie Institute of Technology, Pittsburgh, has been Vice-President of The Electrochemical Society for the past two and one-half years. Dr. Warner joined the Society in 1922 and, among other activities, has served on the Publication, Weston Fellowship, and the Roeber Research Fund committees.

Dr. Warner's achievements and the scope of his interests attest to his marked ability as an administrator, as well as an educator, scientist, and author. Following his early industrial and teaching experience, he joined the faculty at Carnegie Tech in 1926, became Head of the Department of Chemistry in 1938, Dean of Graduate Studies in the College of Engineering and Science in 1945, and President in July 1950. During this time he contributed much to the program for developing professional education at Carnegie.

During a two-year war leave in 1943–45, Dr. Warner was connected with the Manhattan Project doing confidential work on the purification of plutonium. Later he participated in the operation of the Clinton Laboratories at Oak Ridge. He has long played a prominent role in leading scientific and honorary societies, is author of more than 50 technical papers, and co-author of several textbooks.

Dr. Warner was born in Goshen, Indiana, and attended Indiana University where he received his A.B., M.A., and Ph.D. degrees.

Kenneth G. Compton

Vice-Presidential Candidate

Kenneth G. Compton, of Bell Telephone Laboratories, Murray Hill, New Jersey, was born in Seattle, Washington, on September 27, 1904. He received his B.S. degree from Washington State College and, after working for a short time, returned to obtain the M.S. degree. He then joined the Bell Laboratories as research chemist in electrochemistry. He is currently in charge of the work on corrosion, electrodeposition, organic coatings, adhesives, casting resins, and related problems.

J. C. Warner

During World War II, Mr. Compton served as Consultant to the Chief of Ordnance, the N.D.R.C., the Navy, and the Air Force. He received two citations from the Navy for work on special projects, and has acted in an advisory capacity for various government agencies.

Mr. Compton joined The Electrochemical Society in 1938 and has served on the Executive Committee of the Metropolitan Section for many years as a member and as chairman. He was general chairman of the Convention Committee of the New York meeting in 1949 and is on the Convention Committee for 1953. He also represents the Society on the Inter-Society Committee on Corrosion. Mr. Compton is active in a number of other scientific societies, and has recently headed the Management Committee of the Gordon Research Conferences. His publications and lectures indicate his interest in the Corrosion and Electrodeposition Divisions of the Society.

Sherlock Swann, Jr.

Vice-Presidential Candidate

Sherlock Swann, Jr., is currently Divisional Editor on the JOURNAL for the Electro-Organic Division, and is serving on the following committees of the Society: Acheson Award, Ways and Means, and Constitution and By-Laws.

During his membership in the Society, which began in 1928, Dr. Swann has held many offices and devoted much time to the various interests of the Society. Included in the offices he held are: Manager from 1934 to 1940; Vice-President from 1941 to 1943; and again Manager from 1943 to 1946. He has also been prominent in the Electro-Organic Division of the Society, of which he was Secretary-Treasurer from 1940–42; Vice-Chairman, 1942–44; and Chairman from 1944–46.

Dr. Swann was born in Baltimore, Maryland, and received his B.S. degree from Princeton University in 1922, and his Ph.D. degree in organic chemistry from Johns Hopkins University in 1926. The following year he became a member of the Division of Chemical Engineering, Engineering Experiment Station, University of Illinois, and has been Research Professor of Chemical Engineering at that University since 1941. His principal research is in the field of electro-organic chemistry.

Herbert H. Uhlig

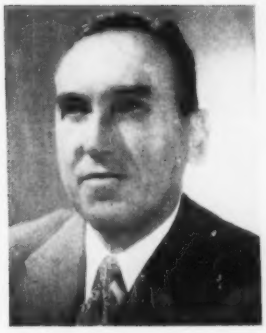
Vice-Presidential Candidate

Herbert H. Uhlig has been active in affairs of the Society since 1937. He has served on several committees, filled various offices, and has been a member

KENNETH G. COMPTON

SHERLOCK SWANN, JR.

HERBERT H. UHLIG



E. G. WIDELL

of the Board of Directors. He received his B.S. degree in chemistry from Brown University in 1929, and his Ph.D. degree from Massachusetts Institute of Technology in 1932. His early research was done at Rockefeller Institute of Medical Research, and Lever Brothers Company in Cambridge. He began research in the field of corrosion in 1936, at Massachusetts Institute of Technology, where he was in charge of the Corrosion Laboratory, investigating stainless steels.

From 1940 to 1946, he was on the staff of the General Electric Research Laboratory, returning to MIT in 1946 as Associate Professor of Metallurgy, heading the Corrosion Laboratory and the teaching of electrochemistry.

Dr. Uhlig is author or co-author of about fifty papers, and is editor of the *Corrosion Handbook*, sponsored by the Corrosion Division of the Society. The *Handbook* has brought the Society more than $12,000 in royalties.

In 1949, Dr. Uhlig was appointed editor of the JOURNAL and served until the spring of this year. He was one of the organizers of the Corrosion Division and has served as chairman of the Corrosion and Theoretical Divisions. In addition, he has been active in other scientific organizations. In March 1951, he received the Willis R. Whitney Award of the National Association of Corrosion Engineers.

E. G. Widell

Candidate for Treasurer

E. G. Widell has been Treasurer of The Electrochemical Society for the past two and one-half years. He became a member of the Society in July 1930, and has served in a variety of capacities since that time.

Mr. Widell was one of the group responsible for the rapid growth of the Electronics Division, acting as Vice-Chairman from 1940–46, and as Chairman from 1947–49. He has also served as Chairman of the Acheson Medal Committee.

Born in St. Paul, Minnesota, he attended the University of Minnesota, receiving the B.S. degree in Chemical Engineering in 1917. Following this, he served in World War I in the Chemical Warfare Service for more than two years, and later received an M.S. degree in Chemical Engineering in 1921 from Massachusetts Institute of Technology.

In 1922, Mr. Widell joined the research staff of the Westinghouse Lamp Division and worked on electron emitters and associated phenomena. In 1930, he became a member of the research staff of the Radio Corporation of America, Victor Division, Harrison, New Jersey, where he has continued his chemical and physical researches in the electronics field. He has published numerous papers on electronics and has been granted many United States and foreign patents on electronic discharge devices.

Columbia-Southern, New Sustaining Member

The Society is glad to welcome the Columbia-Southern Chemical Corporation, with headquarters at Fifth and Bellefield, Pittsburgh, Pennsylvania, as a new sustaining member. This corporation, a wholly-owned subsidiary of Pittsburgh Plate Glass Company, is the nation's largest merchant producer of chlorine and a major producer of soda ash, caustic soda, and related chemicals.

Columbia - Southern has approximately 4,000 employees in plants located at Barberton, Ohio, Corpus Christi, Texas, Lake Charles, Louisiana, Natrium, West Virginia, and Bartlett, California.

Principal operating officers of the corporation are E. T. Asplundh, president; D. R. Means, vice-president and director, and W. I. Galliher, vice-president (sales) and director. J. A. Neubauer is technical director and R. L. Hutchison is general superintendent for the firm.

ASTM Plans 1952 Meetings

The American Society for Testing Materials has announced two meetings for 1952. The Spring Meeting and Committee Week will be held March 3–7 at the Hotel Statler in Cleveland, Ohio. ASTM's Annual Meeting will be held June 23–27 at the Hotels Statler and New Yorker in New York City. At this meeting, which will mark the 50th Anniversary of the Society, there will be an exhibit of testing apparatus and related equipment, and a photographic exhibit. For additional information write to Robert J. Painter, Assistant Secretary, ASTM, 1916 Race Street, Philadelphia, Pennsylvania.

Instrument Society Elects New Officers at Houston

The Instrument Society of America, at its Sixth Annual Instrument Conference and Exhibit held in Houston, Texas, September 10–14, elected the following National officers: *President*—Arnold O. Beckman; *Vice-President*—David M. Boyd, Jr.; *Vice-President*—Robert T. Sheen. Officers still incumbent are: *1st Vice-President*—W. A. Wildhack; *Vice-President*—N. L. Isenhour; *Treasurer*—G. R. Feeley; *Secretary*—Richard Rimbach.

The ISA, formed in 1945 to advance the arts and sciences connected with instrumentation, has attained wide recognition in this field. It now has 51 Sections and some 5,000 members. The recent Conference at Houston, with an attendance of 7,000, and 154 exhibiting companies, was the largest to date.

Paul Manning to Address Chemical Professions

The Third Annual Dinner of the Chemical Professions in Cleveland will be held on Thursday evening, November 8th, at Hotel Hollenden. This is an annual nonprofit affair sponsored by the local chapters of The Electrochemical Society, the American Chemical Society, American Institute of Chemical Engineers, and the American Institute of Chemists, for advancement of the chemical professions in the Northern Ohio area.

The Committee representing the four above-mentioned societies announces that Dr. Paul V. D. Manning, Vice-President in charge of Research at International Minerals and Chemicals Company, will address the meeting. Dr. Manning has had well-rounded experience in teaching, technical publication, research and development, metallurgy, engineering, and plant operation and management.

A large attendance is expected, and the Committee extends a special invitation to the younger men as the occasion will present an excellent opportunity to become acquainted with others engaged in similar work. For reservations, write Stanley Morgan, BenVenue Laboratories, Bedford, Ohio.

SECTION NEWS

New York Metropolitan Section

An unusually good turnout greeted the speaker at the New York Metropolitan Section's first meeting of the new season, held September 26th at the Holley Hotel. Dr. J. W. Cuthbertson, Assistant Director of Research of the Tin Research Institute of England, spoke on electrodeposition of tin alloys. He introduced his subject by reviewing the properties of tin and the advantages to be hoped for from alloying it. These advantages include an improvement in mechanical properties, reduction of porosity, and improvement of tarnish resistance. Tin tends to form compounds rather than solid solutions in most of its systems with other metals. This compound formation complicates the problem somewhat in attempting to deposit alloys. The tin-zinc alloy is an example of a simple eutectic; tin-antimony and tin-cadmium form solid solutions but no very practical work has come out of these two systems as yet. Among the compounds of definite commercial interest are tin-copper and tin-nickel.

The speaker then reviewed the fundamental electrochemical problems of codepositing two metals and the advantages and disadvantages of simple and complex electrolytes. The available tin plating electrolytes were briefly reviewed and their limitations pointed out.

Stannate baths are useful when the other metal can be added as a cyanide; this is the case with zinc and copper. Where cyanide formulations are not practical, the most promising results have been obtained with fluorides. The disadvantages of fluorides from the standpoint of ease of handling are recognized, but seem to be outweighed by the advantages.

Progress in depositing specific alloys was discussed next. The tin-zinc process was reviewed; this is a practical commercial process with many installations in England, on the Continent, and in America.

The tin-copper alloy known as Speculum has been a commercial success to some extent in Great Britain in spite of its limitations. One of these is the fact that the composition of the deposit is very susceptible to the variables such as current density and bath composition, and for this reason the process has not been too successful in job plating but has been used in more repetitive types of work. In particular, its high reflectivity has recommended it as an alternate for silver. Work is being carried out on the possibility of using Speculum as an undercoat for chromium; this has good possibilities, the only drawback so far being that the chromium always comes down dull.

Next to be briefly reviewed were attempts to deposit a practical tin-cadmium alloy. This process proved to be extremely sensitive to the presence of additional agents and the addition agent system was extremely complicated. Furthermore, the properties of the deposit from a corrosion resistance standpoint were somewhat disappointing. (The discrepancy between this report and some work which has been published in this country on the properties of tin-cadmium deposits was pointed out in the discussion.)

The final system considered by the speaker was the tin-nickel alloy. Although the potentials of the two metals in simple salt solutions are fairly close, it was found necessary to use a complexing agent, in this case fluoride ion, in order successfully to codeposit the metals. The nature of the solution used was briefly reviewed; this work will be the subject of a full report by Dr. Cuthbertson at the Detroit convention and he therefore did not go into complete details. One of the outstanding features of this process is the fact that within very wide limits of compositions and operating conditions the deposit remains constant at 65% tin, 35% nickel. This corresponds to a compound NiSn which, however, does not appear in the usual thermal equilibrium diagram. The deposit has some outstanding properties including excellent tarnish resistance and throwing power and a plate which is bright as deposited without the addition of any brightener. Anodic replenishment is by the use of separate anodes of tin and nickel.

A lively discussion period followed in which the members of the audience expressed a great deal of interest in the results discussed.

F. A. LOWENHEIM, *Secretary*

Niagara Falls Section

The first meeting of the season was a social get-together, held on September 12, 1951, at the Youngstown Yacht Club, Youngstown, N. Y.

Acquaintances were made and renewed around an excellent buffet supper. An after-dinner speech on a timely topic, not electrochemical this time, was extremely well accepted. The popularity of this type send-off meeting was attested to by record attendance.

The speaker for the occasion was John van Lonkhuyzen, Chief Guided Missiles Engineer for Bell Aircraft Corporation. Experimental engineering has been Mr. van Lonkhuyzen's principal assignment since he came to Bell Aircraft in May 1942. He worked on the design of the Bell F-63 King-cobra, the F-59, this nation's first jet-propelled fighter, and the X-1, the world's first supersonic airplane. Guided missiles have been his field since 1945.

Born in the Netherlands, Mr. van Lonkhuyzen has attended American colleges and universities. Mathematics was and is his forte.

An abstract of his talk "Guided Missiles" follows:

The assignment of large military budgets, the appointment of Mr. K. T. Keller to control guided missile production, and the allocation of funds for production facilities all point to the imminent introduction of guided missiles into the arsenals of this country. The Germans made the first great strides in guided missile development, not only with the V-2 but also with the antiaircraft missile Wasserfall, the trans-

Atlantic bombardment missile A9/A10, and others. There is no doubt that the Russians have lost little time in continuing where the Germans left off, having acquired most of their skilled manpower and special facilities.

Several phases of development in guided missiles were broadly outlined, among them; operations, research, liquid fuel rockets, automatic control, and radar guidance. The application of the guided missile simulator in development work was described.

A graphic, step-by-step description of the events which take place in the launching of a test missile on one of the military ranges was given. The fact that missiles are "one-shot" affairs, and therefore cannot be systematically tested to remove malfunctions, was stressed, and the effect of this on missile development and the number of trial firings required was outlined.

Finally, a brief statement of the engineer's interest in space travel and the conception of the earth satellite or space platform was given.

H. R. Oswald, *Secretary-Treasurer*

Pittsburgh Section

New officers who have been elected by the Pittsburgh Section for the 1951–52 season are as follows:

Chairman—J. M. Guthrie
Vice-Chairman—M. T. Simnad
Secretary-Treasurer—R. D. Williams

M. T. Simnad,
Secretary-Treasurer (1951)

San Francisco Section

At its final spring meeting in June, the San Francisco Section elected the following officers for the new 1951–52 season:

Chairman—Edward B. Sanigar
Vice-Chairman—George B. Scheer
Secretary-Treasurer—R. F. Bechtold

R. F. Bechtold, *Secretary-Treasurer*

Washington-Baltimore Section

The Washington-Baltimore Section held its annual family picnic on Saturday, September 8. Approximately eighty were present, with half of this number being children. Everybody enjoyed the informal sports during the early part of the afternoon, and the well-prepared picnic supper served by the entertainment committee.

The Section wishes to announce that at the next meeting, on November 15th, a series of three talks will be presented, with Dr. Mortimer C. Bloom of the Naval Research Laboratory as moderator. The talks will be on the important aspects in the present-day research on the flow of electricity through solids. The present status of research in the following fields will be surveyed:

"Semiconductor Rectifiers" by Dr. Robert B. Breckenridge of the National Bureau of Standards.

"Phosphors" by Dr. James H. Schulman of the Naval Research Laboratory.

"Permeability at High Frequencies" by Dr. George T. Rado of the Naval Research Laboratory.

J. C. White, *Secretary-Treasurer*

PERSONALS

J. M. Bialosky has left United States Steel Company, Pittsburgh, to accept the position of Corrosion Engineer in the Development Section of the Research Department at Koppers Company, Inc., Pittsburgh.

George W. Murphy is on a year's leave of absence from the University of Wisconsin to do research at Argonne National Laboratory, Chicago, under the Cooperating Institutions Program.

H. D. Wilson has been promoted from Chief Engineer of the Battery Division to Chief Chemical Engineer of The Electric Auto-Lite Company, Toledo, Ohio.

B. C. Case, named manager of Electrochemical Development, Hanson-Van Winkle-Munning Company, is now at the Matawan, N. J. plant.

C. P. Love has been transferred to Kaiser Aluminum & Chemical Corporation, New Orleans, La., from the company's plant at Tacoma, Wash.

C. F. Pogacar of Pittsburgh has recently accepted a position with the Atlantic Refining Company, Philadelphia, Pa.

C. L. Mantell, Chairman of the Department of Chemical Engineering, is giving the graduate course in Electrochemical Engineering for the second successive year at Newark College of Engineering, Newark, New Jersey. Dr. Mantell's book "Industrial Electrochemistry" is now in its third edition. It is interesting to note that there are four thesis students on electrochemical research, and that the Chairman of the Board of Trustees of the College is Mr. Edward Weston, the son of the Edward Weston who founded the Weston Fellowships of The Electrochemical Society.

HENRY HOWARD

Henry Howard, a charter member of The Electrochemical Society, and one of the pioneers of American chemical industry, died on August 25th.

Starting his career as an analytical chemist for the Merrimac Chemical Company near Boston, Mr. Howard remained there for 32 years, during which time he was instrumental in establishing processes in this country for the manufacture of sulfuric acid, alumina hydrate, and aluminum. In the early years he made various trips to Europe to study chemical advances there. Later Mr. Howard was connected with the Grasseli Chemical Company.

He invented the Howard dust chamber and, during his lifetime, took out some 89 patents. He was the recipient of the Perkin Medal and other honors, and served for 40 years as a member of the corporation of Massachusetts Institute of Technology.

Mr. Howard was born in Jamaica Plain, Boston, on July 5, 1868.

NEW MEMBERS

In September 1951 the following were elected to membership in The Electrical Society:

Active Members

John O'M. Bockris, Imperial College, London S.W. 7, England (Theoretical Electrochemistry)

George J. Goepfert, Speer Carbon Company, St. Marys, Pa. (Industrial Electrolytic)

Sudarshan D. Gokhale, India Government Mint, mailing add: 176A, Parshuramwadi, Girgaum, Bombay 4, India (Electrodeposition, Electrothermic, and Industrial Electrolytic)

Lucien E. Meunier, Faculte Polytechnique de Mons, mailing add: 7 rue de Mons, Hyon, Belgium (Theoretical Electrochemistry)

Norio Miyake, Matsushita Electric Industrial Company, mailing add: 30, Matsushitacho, Moriguchishi, Osakafu, Japan (Battery)

James F. Murphy, Kaiser Aluminum & Chemical Corporation, Division of Metallurgical Research, P.O. Box 1451, Spokane 6, Wash. (Battery,

Corrosion, Electrodeposition, Electronics, Industrial Electrolytic, and Theoretical Electrochemistry)

P. S. NARAYANA, Engineering & Mineral Industrial Research Laboratory, mailing add: Mines House, Bangalore 3, India (Electric Insulation, Electrodeposition, Electrothermic, and Industrial Electrolytic)

R. NATARAJAN, Mettur Chemical & Industrial Corporation Ltd., Mettur Dam, R. S., India (Electronics and Industrial Electrolytic)

ROBERT M. PARKE, Battelle Memorial Institute, 505 King Avenue, Columbus 1, Ohio (Electronics)

EDMUND C. POTTER, The Paint Research Station, mailing add: 31, Burnaby Gardens, Chiswick, London W. 4, England (Corrosion and Theoretical Electrochemistry)

ROBERT A. POWERS, National Carbon Research Laboratory, mailing add: 3666 W. 116 St., Cleveland 11, Ohio (Battery, Corrosion, and Theoretical Electrochemistry)

MICHAEL J. PRYOR, National Research Council, Applied Chemistry Division, Ottawa, Canada (Corrosion)

JUAN R. REGULI, University of Montevideo, mailing add: Yatay 1525, Montevideo, Uruguay (Corrosion, Electrodeposition, Electronics, Electro-Organic, Electrothermic, Industrial Electrolytic, and Theoretical Electrochemistry)

BERNARD RUBIN, National Bureau of Standards, mailing add: 1535 Upshur St., N.W., Washington, D. C. (Theoretical Electrochemistry)

JOHN H. SCHLOEN, Canadian Copper Refiners Ltd., P.O. Box 489, Place d'Armes, Montreal, Quebec, Canada (Industrial Electrolytic)

MANEKLAL S. THACKER, Indian Institute of Science, Bangalore 3, India (Battery, Electric Insulation, Electronics, and Theoretical Electrochemistry)

Reinstatements

EDWARD CALDERON, 973 Rosecrans St., San Diego 6, Calif. (Electrodeposition)

EARL J. SERFASS, Department of Chemistry, Lehigh University, Bethlehem, Pa. (Electrodeposition)

Associate Members

WOODWARD G. EICKE, JR., National Bureau of Standards, mailing add: 202 Webster St., N.E., Washington 17, D.C. (Battery)

EDWARD E. CONRAD, National Bureau of Standards, mailing add: 5049 Bradley Blvd., Bethesda, Md. (Electric Insulation, Electronics, and Theoretical Electrochemistry)

LESLIE A. PRODAN, Mathieson Chemical Corporation, mailing add: Box 851, Falls Station, Niagara Falls, N. Y. (Industrial Electrolytic)

BALKUNJE A. SHENOY, Central Electro-Chemical Research Institute, Sekkalai P.O., Karaikudi, S. Rly, India (Corrosion)

LEE P. STEPHENSON, University of Illinois, 203 Physics Laboratory, Urbana, Illinois (Theoretical Electrochemistry)

Student Associate Members

ZENON W. POKVITIS, Avildsen Tools & Machines Inc., mailing add: 5640 Netherland Ave., Riverdale 71, N. Y. (Electrodeposition)

WILLIAM N. VANDERKOOI, Calvin College, mailing add: 1211 Sigsbee S.E., Grand Rapids, Mich. (Theoretical Electrochemistry)

EMPLOYMENT SITUATIONS

Please address replies to box shown, c/o The Electrochemical Society, Inc., 235 West 102nd Street, New York 25, N. Y.

Positions Wanted

METALLURGIST, B.S. (Chem.), postgraduate work in metallurgy. Research and process development experience in the application of leaching, furnace, and electrolytic methods to the recovery of and refining of copper, lead, tin, silver, cadmium, and other nonferrous metals. Experience, metals powders. *Reply to Box 345.*

RESEARCH DIRECTOR. Metallurgical chemist, with broad experience in metal finishing, electroplating, corrosion, ferrous and nonferrous metallurgy, and quality control, seeks equivalent position. *Reply to Box 346.*

Positions Available

METALLURGIST OR ELECTROCHEMIST

The Naval Air Material Center, Naval Base, Philadelphia 12, Pa., has an opening for a Metallurgist or Electrochemist. Salary will be $6400 per annum. Duties of the position, in general, are to supervise a small development group engaged in work on electrodeposited matallic coatings, corrosion studies as applied to aircraft alloys and components, and surface treatments for the promotion of improved paint adhesion. Supervision of engineering personnel is prerequisite background experience. Write to the Industrial Relations Department, Naval Air Material Center, Naval Base, Philadelphia 12, Pa., for an application for employment.

B.S. OR M.S. CHEMIST, CHEMICAL ENGINEER, OR METALLURGIST, with several years of practical experience in metal finishing, for process development and technical service work in modern light metals research laboratory located in Pacific Northwest. Please give specific details of education, experience, salary requirements, and availability date. All inquiries treated in confidence. *Reply to Box A-233.*

ENGINEER to solve corrosion problems in process equipment and plant maintenance by proper metal selection, protective coatings, fabrication procedures. Five to 10 years' experience plus B.S. or M.S. in Chemical, Metallurgical, or Mechanical Engineering desired. Position is with stable, well-established, consumer products industry in East. Salary open. State complete details of experience, responsibility carried, and age, in first letter. *Reply to Box A-234.*

RECENT PATENTS

Selected for electrochemists by Fred W. Dodson, Chairman of the Patent Committee, from the Official Gazette.

July 24, 1951

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